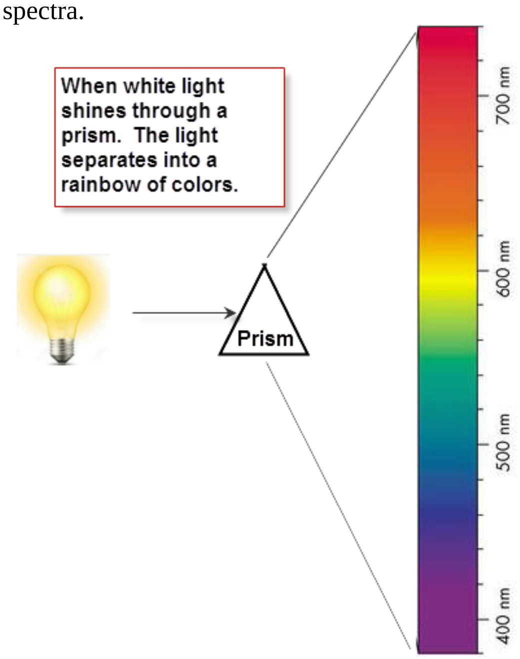
Set 11. Relationship between wavelength, frequency, energy, and light

Skill 11.01: Understand the relationship between wavelength, frequency and light "color"
Skill 11.02: Calculate the wavelength, given the frequency and vice versa
Skill 11.03: Understand the relationship between energy, wavelength, and frequency
Skill 11.04: Calculate the energy of light given the frequency or wavelength

Skill 11.01: Understand the relationship between wavelength, frequency, and light color

From fireworks to stars, the color of light is useful in finding out what's in matter. The emission of light by hydrogen and other atoms has played a key role in understanding the electronic structure of atoms. Trace materials, such as evidence from a crime scene, lead in paint or mercury in drinking water can be identified by heating or burning the materials and examining the color(s) of light given off in the form of bright-line spectra.



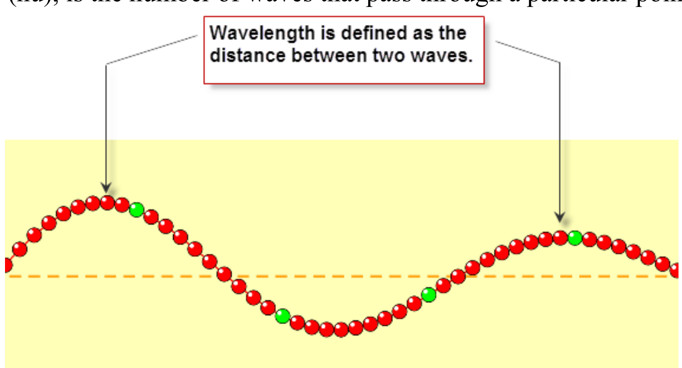
Skill 8.01. Problem 1

Refer to the figure shown to the right. Identify the range of wavelengths associated with each color. The "Reds" have already been filled in.

Color Range	**Wavelengths**
Reds	680–740
Oranges	
Yellows	
Greens	
Blues	
Violets	

Light consists of **electromagnetic waves**. Electromagnetic waves are characterized by their wavelength and frequency:

- The **wavelength**, λ (lambda) is the distance between identical points on successive waves.
- The **frequency**, ν (nu), is the number of waves that pass through a particular point in one second.

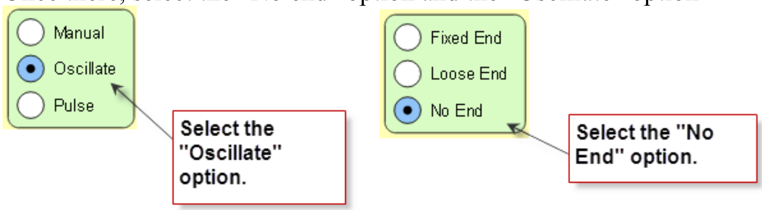


Skill 11.01 Problem 1

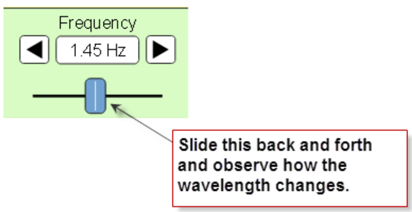
Navigate to the wave on a string simulator.

http://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html

Once there, select the “No end” option and the “Oscillate” option



(a) Locate the frequency slider. Move it back and forth and observe how the wavelength changes.



(i) When you increase the frequency, what happens to the wavelength? Does it increase or decrease?

(ii) When you decrease the frequency, what happens to the wavelength? Does it increase or decrease?

(iii) What is the relationship between frequency and wavelength? Is it inverse or direct?

Skill 11.01 Problem 2

Refer to the colors below. Sort the colors from low to high with respect to frequency.

Color Range	**Order of frequency (1 = lowest)**
Reds	
Oranges	
Yellows	
Greens	
Blues	
Violets	

[**Skill 11.01 Exercises 1 & 2**]()

Skill 11.02: Calculate the wavelength, given the frequency and vice versa

All electromagnetic waves travel at the same speed (3.00×10^8 m/s). This speed is referred to as the speed of light. By convention, the symbol, c, is used for the speed of electromagnetic radiation. The speed, c, of an electromagnetic wave is the product of its wavelength and frequency,

$$c = \lambda \nu = 3.00 \times 10^8 \text{ m/s}$$

Skill 11.02 Problem 1

For each of the colors below,

(a) Indicate the average wavelength in nanometers (nm)
(b) Convert each wavelength to nanometers (1×10^{-9} m = 1 nm)
(c) Calculate the frequency

Color Range	**Average λ (nm)**	**λ (m)**	**ν (/s)**
Reds	710 nm	$710\text{nm} \times \frac{1\text{m}}{1x10^9\text{ nm}} = 7.10 \times 10^{-7}\text{ m}$	$\frac{3.00 \times 10^8\text{ m/s}}{7.10 \times 10^{-7}\text{ m}} = 4.23 \times 10^{14}\text{ /s}$
Oranges			
Yellows			
Greens			
Blues			
Violets			

(a) Are the wavelengths of ultra-violet light longer or shorter than that of visible light?

(b) Are the frequencies of ultra-violet light longer or shorter than that of visible light?

(c) Are the wavelengths of infra-red light longer or shorter than that of visible light?

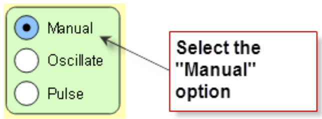
(d) Are the frequencies of infra-red light longer or shorter than that of visible light?

Skill 11.02 Exercise 1

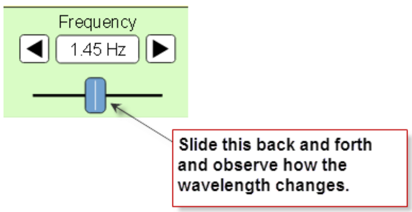
Skill 11.03: Understand the relationship between energy, wavelength, and frequency

Skill 11.03 Problem 1

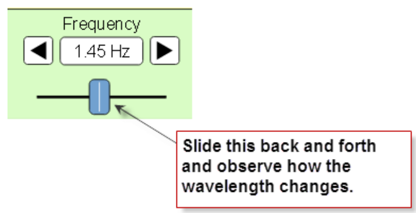
Now return to the simulator (http://phet.colorado.edu/sims/html/wave-on-a-string/latest/wave-on-a-string_en.html) Select the "Manual" option.



Move the wrench up and down as fast as you can and observe the wavelength. Now move the wrench up and down slowly and observe the wavelength.



(i) When you moved the wrench up and down quickly (high energy), what happened to the wavelength? Did it increase or decrease?



(ii) When you moved the wrench up and down slowly (low energy), what happened to the wavelength? Did it increase or decrease?

(i) What is the relationship between energy and wavelength? Is it inverse or direct?

Skill 11.03 Problem 2

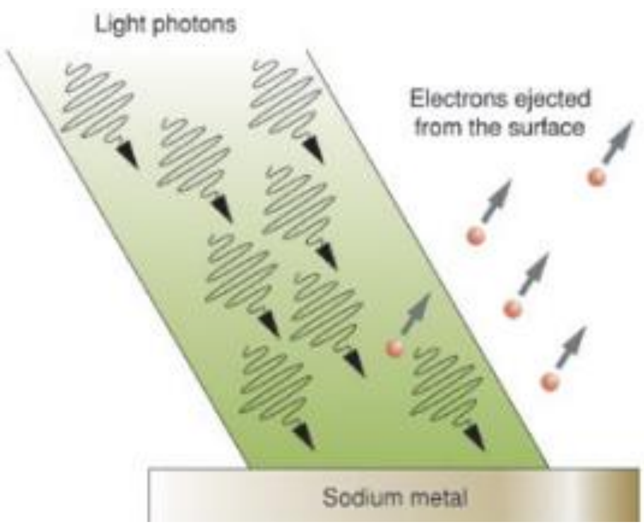
Refer to the colors below. Sort the colors from low to high with respect to energy.

Color Range	Order of energy (1 = lowest)
Reds	
Oranges	
Yellows	
Greens	
Blues	
Violets	

Skill 11.03 Exercises 1 & 2

Skill 11.04: Calculate the energy of light given the frequency or wavelength

Max Planck and Albert Einstein showed that light could be viewed as a stream of particles or photons, or a particle. This concept is illustrated below,



The picture above shows that when a metal receives sufficient energy (packet), electrons can be ejected as packets of energy. The packets of energy absorbed by the metal are referred to as photons.

The energy of a single photon (or packet of energy) in joules (J) is given by:

$$E = h\nu$$

Where, h, is called Planck's constant and is equal to 6.63×10^{-34} J·s and v is the frequency of the radiation.

Skill 11.04 Problem 1

Refer to problem 11.02 Problem 1

(d) For each color, copy the corresponding frequency

(e) Calculate the energy in joules

Color Range	**frequency ν**	**Energy (J)**
Reds	4.23×10^{14} /s	$(6.63 \times 10^{-34}\, J \bullet s)(4.23 \times 10^{14}\, /s)$ $= 2.80 \times 10^{-19}\, J$
Oranges		
Yellows		
Greens		
Blues		

Violets			

(a)	How do the energies of ultra-violet compare to visible light?
(b)	How do the energies of infra-red light compare to visible light?

Skill 11.04 Exercise 1